AC 2012-3529: THE RUBBER BAND RULE AND OTHER INNOVATIVE TECHNIQUES TO TEACH INTRODUCTORY CIRCUIT ANALYSIS

Prof. James E. Globig, University of Dayton

James Globig joined the University of Dayton in Aug. 1998 after nearly 20 years of engineering experience in a variety of product-producing organizations. Having held positions ranging from Design Engineer to Vice President of Research and Development, he combines a practical and thorough understanding of the product development process and the role of the engineer in corporate America. He is named on eight patents. Globig received his bachelor's of engineering technology from the University of Dayton in 1979, his master's of business administration from Miami University in 1983, and his master's of science from University of Dayton in 2003. He teaches a number of lecture and laboratory courses in circuit analysis, semiconductor devices, and data acquisition and control.

Prof. Michael J. Kozak, University of Dayton

Michael Kozak is an Assistant Professor in the Department of Engineering Technology at the University of Dayton. He primarily teaches classes related to mechanical engineering technology, and his main research interest is in pedagogy.

The Rubber Band Rule and Other Innovative Techniques to Teach Introductory Circuit Analysis

Introduction

First year engineering and technology students often struggle with the most fundamental concepts of circuit analysis. Textbooks often have numerous examples of "what" the various circuit examples look like but sometimes fall a bit short of "how" to go about solving them and how to retain that methodology to memory. In addition, some circuit analysis principles are so obvious to the experienced engineer - author that they are overlooked or skimmed over in textbooks. These instructors have found that a number of simple concepts, when presented in relaxed classroom or individual problem solving sessions, often "turn the lights on" for the beginning circuits student.

First Class Meeting - Anxiety Reduction

At the very first class meeting, the instructor tries to remove the anxieties of first year Circuits (affectionately called "Snircuits" by the instructor) students. Many of these students, especially the non-majors, are quite intimidated by Electrical Circuits even at the most fundamental level because they can't "see" what's happening before them. A significant portion of the non-majors are taking the course for the second time and / or have avoided taking it until they are upper classmen increasing their anxiety ever further.

In the first session, the instructor does *not* review the syllabus, etc. To some of the students the syllabus is the only subject at the university that is more boring than the subject of circuits itself! Instead, circuits are introduced using "batteries" and "light bulbs;" components that are readily familiar to every college student. One must not forget to introduce the symbols for a battery (DC power source) and light bulb (resistor). Two formulas are introduced: E=I*R and P=E*I. A few simple examples are worked. *It is made clear that the great majority of the course incorporates only those two formulas* albeit in various forms. It is at this point that bright red "ET Elite" pencils are introduced. Throughout the semester, as the instructor interacts with the students, pencils are given to students who are able answer the more challenging questions asked by the instructor. This provides a remarkable amount of incentive to engage and motivate all of the students.

Near the end of the first session, homework is assigned. Beginning the first session immediately with circuit analysis and ending with a homework assignment serves to send a message to the first year student that, although we are going to have some fun, "We aren't in Kansas anymore, Toto!"

At the end of the first session, extra time is allowed for questions – any questions the students have for the instructor; feedback on teaching style, concerns they may have heard from other students, etc. The very last point made by the instructor before adjournment is that passing the course is a give and take proposition. If the student attends every class meeting (unless excused) and turns in every homework, then the instructor promises to spend as much time with the student outside of class, as is required, to help them do their best or at the very least, pass the course.

Teaching Circuit Analysis

"Begin at the End"

This is a similar to Boylestad's Reduce and Return Approach.[1] Although this approach is described in detail in an example problem (one of countless excellent examples in Boylestad) nowhere is it explicitly stated that one *begins* the circuit analysis and reduction *at the end* of the circuit opposite the source. Likewise, Nilsson starts at the end of the circuit but doesn't explicitly state a methodology[2]. Monier doesn't offer a methodology for circuit analysis either and actually begins the analysis in the middle of the circuit[3]. Hence the instructor uses and repeats throughout the course "begin at the end." In Boyleastad's General Approach,[4] He states:

> "2. Examine each region of the network independently before tying them together in series-parallel combinations. This usually simplifies the network and possibly reveals a direct approach to obtaining one or more desired unknowns. It also eliminates many of the errors that may result due to a lack of a systematic approach."

Although this approach is undoubtedly quite effective for the more experienced in circuit analysis, the instructor does not encourage the beginning circuit analysis student to take this approach. Consider Figure 1 below:

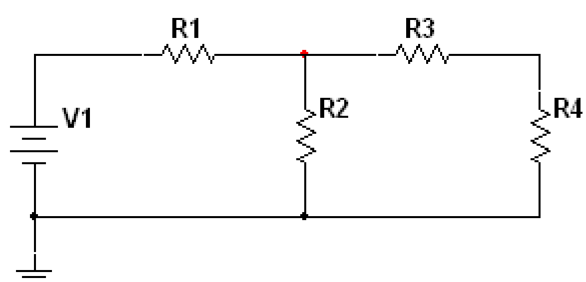

Figure 1

Using this approach, the beginning Circuits student invariably wants to put R2 in series with R1 *first* before taking R3 in series with R4 and then taking that simplification in parallel with R2. Instead, the instructor suggests that the beginning student go to the opposite end of the source and always begin the systematic approach there. Although this approach clearly has some weaknesses for circuits where sources are interior to the circuit, the instructors have found that starting the student out this way sets the stage for early circuit analysis success.

“Flappin’ in the Wind”

By this point in the course, the instructor and student have worked tirelessly to understand that every time we see a resistor in a circuit there’s going to be a voltage drop. This is the time to reinforce the concept that *current causes voltage drops* (it’s that darn E= I*R thing again). A person experienced in circuit analysis may try to teach them that if the resistor is not connected (flappin’ in the wind) then there is no voltage drop. More appropriately, the instructor first identifies: Is there current flowing. If the answer is no, then the resistor is “flappin’ in the wind” and there is no voltage drop. Consider Figure 2 below:

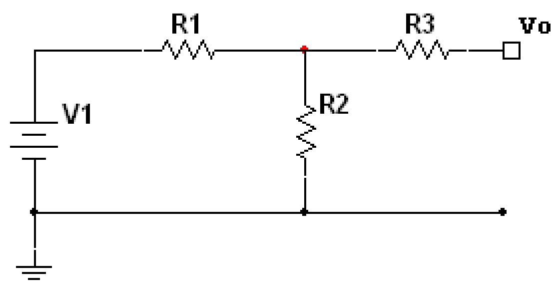

Figure 2

The instructor repeatedly associates an open circuit with “flappin’ in the wind” meaning “no current flow, no voltage drop” where Vo = V_{R2}.

The “Rubber Band Rule”

Consider Figure 3[5]:

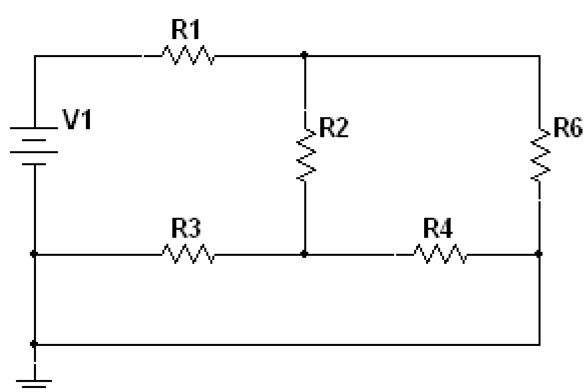

Figure 3

Students try to solve this series-parallel circuit every which way. But one thing for certain; R3 and R4 are definitely in series: NOT! To solve circuits like these, first we utilize Boylestad’s General Approach number 1[6]:

"1. Take a moment to study the problem "in total" and make a brief mental sketch of the overall approach you plan to use. The result may be time and energy saving short cuts."

To teach the recognition whether two components are in parallel, first the instructor calls yet again upon Boylestad; "two elements, branches, or circuits are in parallel if they have two points in common."[7]An instructor can't help but to love this one! It is short, sweet, simple, and you can't go wrong. It remains a mystery to the author's why some students still don't get it! Hence we must dig down into our pedagogical tool box and utilize Einstein's Rubber Band Rule (Many students really aren't sure whether the instructor is spoofing them or not on this one). The rule works as follows: assume that all of the connecting wires in a circuit are half taut rubber strands. Provided they are not be disconnected and reattached in any way, the component may be moved around to minimize the average length of the wires or until the sub-circuit's relationship to its neighbors becomes obvious. Consider Figure 4 below as the clarification and simplification of Figure 3 utilizing the infamous Rubber Band Rule.

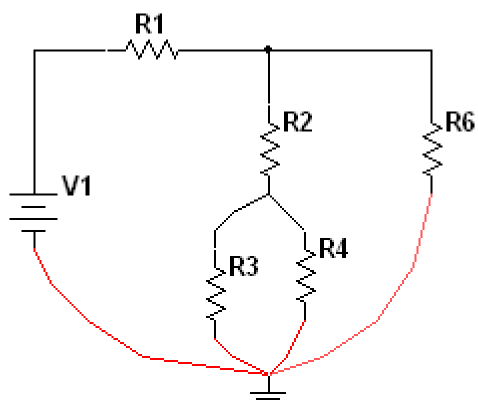

Figure 4

AC Circuits

"RMS is Less," "The highest Peak"

Even after deriving the origin of rms versus peak voltage and current, students can't seem to remember which is which. However, they do remember they must multiply or divide by .707 to get there. The mnemonics above help. What also helps is to mix rms and peak terms in circuits on their exams until they get it right. Consider the circuit in Figure 5 below:

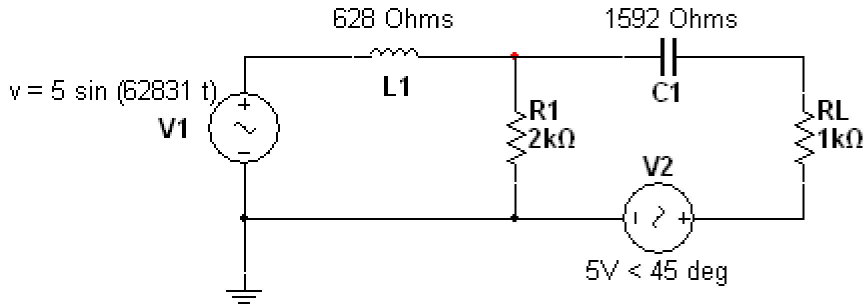

Figure 5

When exposed to this stunt the first time, the great majority of students will try to solve the problem assuming that the power sources are both either 5Vp or 5Vrms. Some readers might consider this student cruelty. However if one has ever been in industry and working on a circuit board with mixed power, analog and digital circuits one would understand how difficult technical communication is unless one is very specific concerning the units being used.

You Can't Buy a 628 Ω Inductor at Radio Shack

Considering Figure 5 again, many authors simplify their practice problems by pre-calculating the reactance of the components [8,9,10]. Before the instructor changed the way impedance was presented, he often observed students searching for 628Ω inductors in the laboratory parts drawers. In an effort to keep the course as practical as possible, the instructor rarely works a circuit on the board and never puts a circuit on the test where the capacitor and inductor units aren't Farads and Henry's. Students are always required to calculate the correct impedances before beginning AC circuit analysis. The mnemonic "**C**apacitors **A**in't **P**ositive" is helpful for students to remember and calculate the phase angles of the impedance of capacitors and inductors alike. Regardless of the calculator used, it is highly recommended to enter all impedances inside parentheses in order to avoid the confusion associated with incorrect order of operations issues. See Figure 6. Finally, the well known mnemonic "ELI the ICE man" is demonstrated to the student as a way to remember the phase relationships in inductive and capacitive circuits and is especially useful when graphing AC voltages and currents.

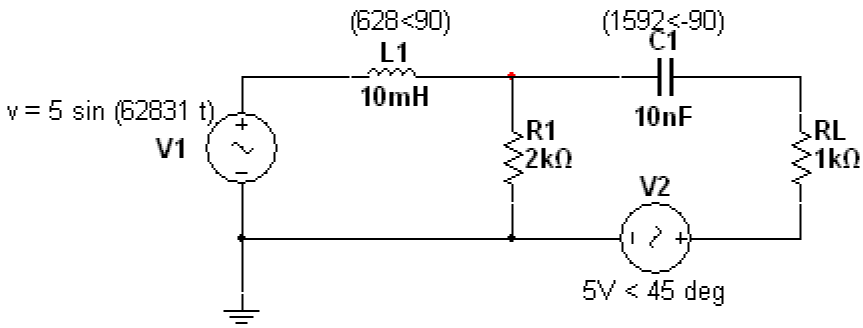

Figure 6

The Making of a “Nodaholic”

For a number of reasons, students tend to favor Mesh Analysis over Nodal Analysis techniques. At this stage in their engineering education, many students still tend to be less than comfortable with engineering notation, especially when the powers of ten are negative. In addition the coefficients to the Nodal equations are in Siemens instead of Ohms adding another level of discomfort. Finally, they find the concept of a node more confusing than that of a loop.

Students tend to visualize a node as a specific point on a circuit. Therefore when a node has more than three or so branches, they sometimes want to make multiple nodes out of a single node or ignore the extra branches altogether. Consider Figure 7:

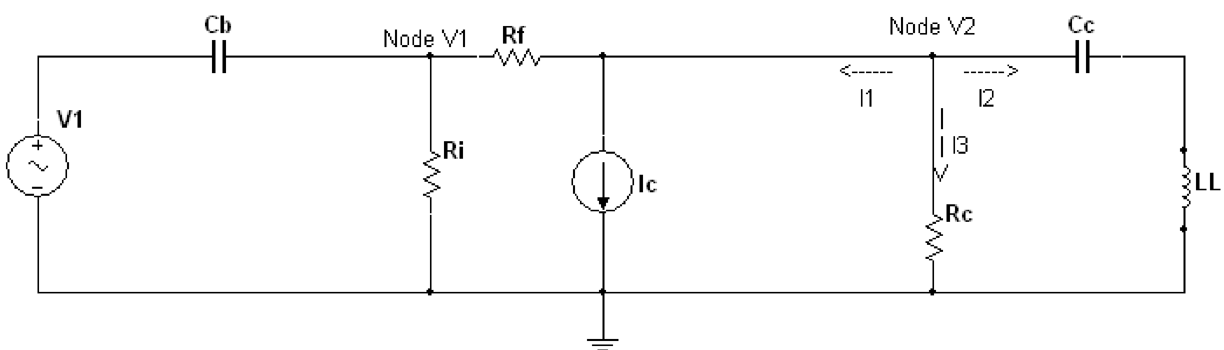

Figure 7

Many students will conclude that Node V2 has only three currents associated with it instead of four. To further clarify the concept of a Node, the instructor highlights each node right up to each component on that node as seen in Figure 8.

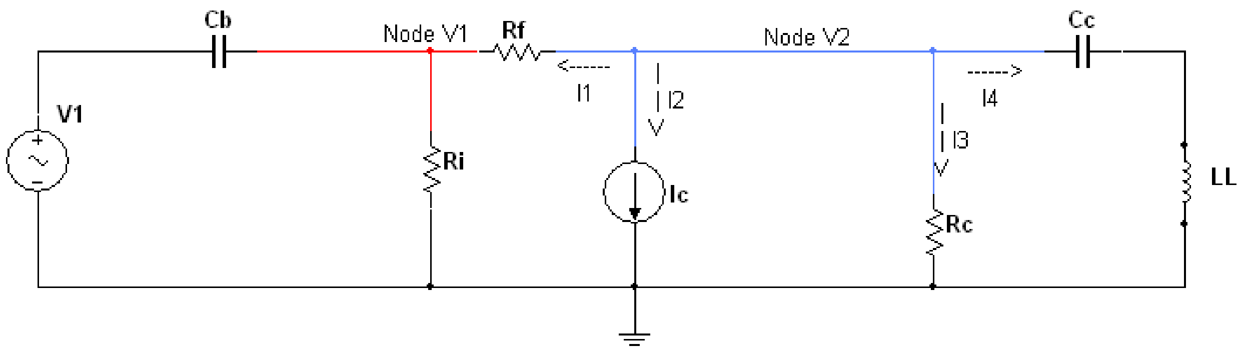

Figure 8

This technique not only clarifies what a Node is but also that currents can and do enter and leave the same Node at very different points.

Because Nodal Analysis can be readily utilized with both voltage sources and current sources, it is actually the more versatile of the multi–source, multi–node, multi-loop circuit analysis techniques. When utilized in calculating Thevenin's equivalent circuit (See Figure 9). E_{TH} can often be calculated directly using Nodal Analysis.

Open Your Is

When learning Thevenin's and Norton's equivalent circuits, students often have a difficult time remembering whether the voltage sources and current sources get shorted or opened. "Open your Is" helps them remember to open current sources (and short voltage sources) when calculating the equivalent impedance as seen in Figure 9.

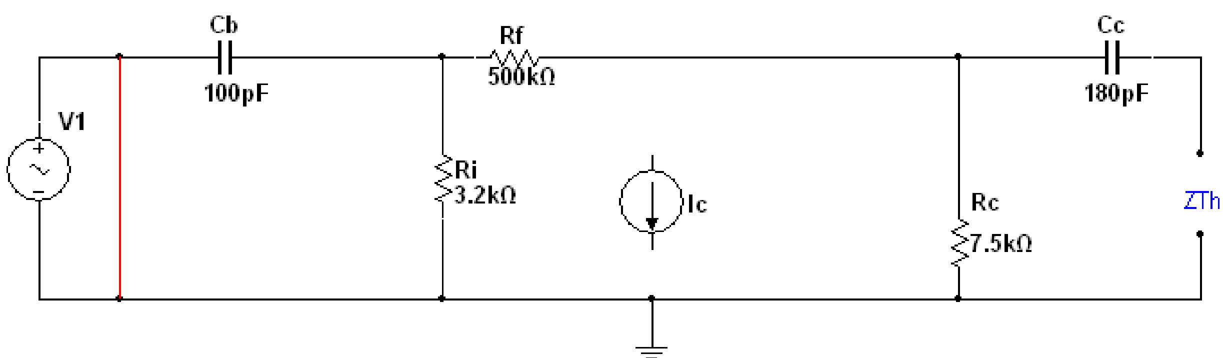

Figure 9

Also at this point in the course, students learn to begin utilizing various techniques when analyzing a circuit. As mentioned above, utilizing Nodal analysis to directly calculate E_{TH} as in Figure 10, further demonstrates the versatility of Nodal analysis techniques.

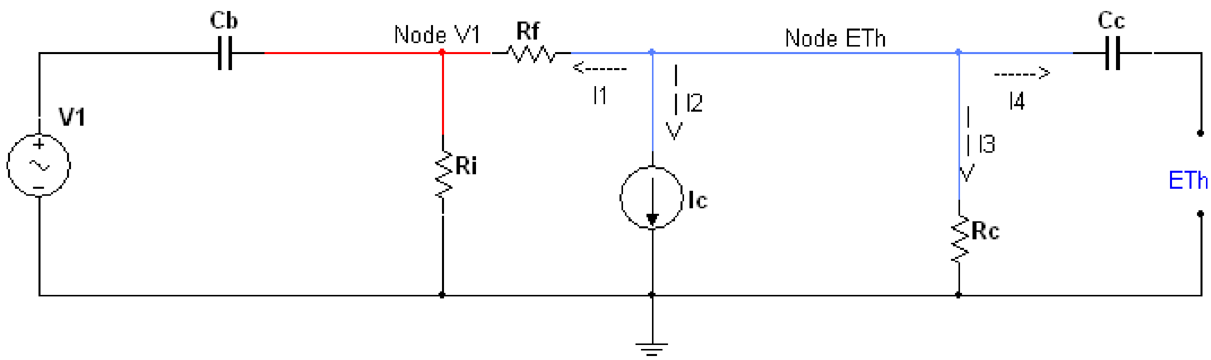

Figure 10

Course Assessment - Student Perceptions

At the end of each term, students are asked to complete a fairly detailed survey of their assessment of each course in the School of Engineering. The survey is utilized by faculty to make course improvements and also as input to their annual performance evaluation.

Survey Responses:

Responses to three of the survey questions (questions 12, 13, and 23) are tracked semester to semester. The range of the scale is; 0 = strongly disagree to 4 = strongly agree. The Course Average is the average of student responses for that question for the Course Title and Term indicated. The Department Average is the average score for the same question for all courses taught by ten faculty members in the Department of Engineering Technology.

			12. I learned a great deal from this course		13. I would recommend this course to other students.		23. I would recommend this instructor to other students.	
Term	Course Title	No. of Evals	Course Avg.	Dept Avg.	Course Avg.	Dept Avg.	Course Avg.	Dept Avg.
Fall ‘10	Circuits II	13	3.6	3.3	3.2	3.1	3.4	3.4
Fall ‘09	Circuits I	18	3.6	3.2	3.2	3.0	3.4	3.2
	Circuits II	20	3.3	3.2	3.2	3.0	3.4	3.2
Fall ‘08	Circuits I	18	3.6	3.2	3.2	3.0	3.2	3.2
	Circuits II	20	3.3	3.2	3.2	3.0	3.3	3.2
Fall ‘07	Circuits II	17	3.7	3.1	3.3	2.9	3.8	3.1

Selected student comments pertaining to the subject matter of the paper:

Question 31. What elements of this course increased your knowledge and or/understanding?

- The instructor’s examples in class.
- Relation to real-life situations.
- The entire course is well taught.
- I really enjoyed this class the professor made it really fun to understand the subject of circuit analysis with ease.

- Classroom discussion.
- His in class examples is the best way to learn the material, not the book.
- The way professor ______ taught, helped with my understanding.

Question 32. What elements of this course need improvement? Explain disagree or strongly disagree marks for statements 1 to 30.

- I feel the course is very good. The class is taught well, simply the material is hard. Therefore I don't think there is anything that needs improvement.
- Enjoyable course. Nothing needs to be changed in my opinion.
- I don't think this class can improve. It is such a great class.
- I felt a disconnect between the processes in the book vs. what he talked about. His processes did make more sense than the book.

Question 33. Further comments:

- I thought I would do awful in this class, & would dislike the class but ______ is a really good teacher. I learned a lot & really enjoyed it!
- Very hard class, able to understand in-class material but tests are difficult even with a lot of study time. Good teaching style.
- Good Job! You have a way to relate the material to students on their level and you never assume students already know some things.
- Giving out pencils is a cool motivational tool, and makes you feel like you've actually accomplished something. The class is very good, and the instructor is extremely personable and helpful. He has excellent charisma.
- ______ is very good at teaching a class, keeping us awake with quirky comments or jokes, but he is also a tough teacher. His exams are tough. Overall I'd say Professor is tough but fair.
- Although I'm not a big fan of circuits, I enjoyed the class and the time spent in it. The pencils are fun and a good motivation. ☺ When I needed extra help ______ was always available to teach me what I didn't understand in class.
- Snircuts. Yeah baby.
- This teacher is great on his explanations and he is just a fun man to have in class.
- Professor ______ is a professor who knows what he is talking about and enjoys it. The grading is just rough in my opinion.
- ______ really improved my thought processes + critical thinking. I enjoyed his in your face teaching style.

Negative student comments were primarily associated with hard grading, too much homework, and assignments being due on Monday morning.

In conclusion, students seem to be satisfied with the combination of lightheartedness and rigor that this pedagogical approach to introductory circuit analysis provides. The students not only seem to enjoy the instructors pedagogical approach but it also helps them understand material that they thought would be uninteresting or that they would dislike.

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